Exhibit I

NewFields

Expert Report
of
Shahrokh Rouhani, Ph.D., P.E.

IN THE UNITED STATES DISTRICT COURT
DISTRICT OF SOUTH CAROLINA FLORENCE DIVISION

BRYAN L. SHAVER and MELISSA C. SHAVER,
Plaintiffs,

v.

BONSAL AMERICAN, INC. f/k/a OLDCASTLE RETAIL, INC., OLDCASTLE, INC., OLDCASTLE LAWN AND GARDEN, INC., OLDCASTLE BUILDING PRODUCTS, INC., TERRA RENEWAL SERVICES, INC., and DARLING INGREDIENTS, INC., ALABAMA SAND AND GRAVEL, INC. and FERROGLOBE, INC.
Defendants.

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1 INTRODUCTION

1 I have been retained to review, analyze and opine on the reliability, accuracy and validity of an undated expert witness report by Dr. Larry Murdoch, File number 5645-16. To perform this task, I, among other considerations, reviewed and analyzed the methodologies, processes, tests, findings and conclusions presented in Dr. Murdoch's report. I specifically assessed whether Dr. Murdoch's report provides any basis to conclude that any action or inaction by Terra Renewal or Darling Ingredients, Inc. (together, the "Terra Defendants") caused any increase in lead concentrations in the groundwater that entered or flowed through the well at the Plaintiffs' property, *i.e.* the "Shaver well" situated within the "Shaver property".

2 Dr. Murdoch's report is a poorly organized document,[1] which starts by stating: "*My understanding is that industrial sludge was applied to the field north of the well* (the "Kimrey Tract[2]") *and there is a concern that contaminants from the sludge entered the aquifer and flowed to the Shaver well*" (page 2, paragraph 1). Without defining any clear purpose or hypothesis, the report proceeds to present a series of purported statistical test results, followed by a discussion based on a groundwater flow/flow path model ("the groundwater model").[3]

3 My review of Dr. Murdoch's report and the relevant documents, listed in Section 5, indicates that the statements expressed by Dr. Murdoch suffer from a number of statistical and technical flaws, rendering them unreliable and irrelevant regarding the occurrence of lead concentrations measured in samples collected at the Shaver property. These flaws, which are detailed in Section 4, have led me to the following conclusions:

- Statistical tests presented in Dr. Murdoch's report are technically flawed, unreliable, and not conducted in accordance with accepted statistical practices.
- The results of statistical tests presented in Dr. Murdoch's report do not indicate that measured lead concentrations in the Shaver property are significantly different from Dr. Murdoch's background values.[4]
- When Dr. Murdoch's datasets are modified to properly compare only groundwater samples to groundwater samples (as opposed to including samples from the sink and other similar locations within the Shaver property), the measured lead concentrations in the Shaver well in 2016 are not significantly different from Dr. Murdoch's background values.

[1] Dr. Murdoch's report not only lacks a publication date or numbered sections, but also contains two different sections that are labeled as Part 1 and another two different sections that are labeled as Part 2.
[2] The Kimrey Tract contains a number of exploratory mine borings, as displayed in Figure 15 of Dr. Murdoch's expert report, as well as on the second page of Dr. Murdoch's Support Documents 4 (page 29 of pdf file "MURDOCH 1 through 5").
[3] During his deposition of 11/14/2017, Dr. Murdoch admits that he is not providing any expert opinion with regards to the causes of the occurrence of lead concentrations in the Shaver property (Rough Draft, page 20, line 17). Dr. Murdoch also admits that he "*can't testify with any degree of reasonable certainty that any alleged lead in the Shavers' water didn't come from the Shavers' well*" (Rough Draft, page 25, line 2).
[4] Dr. Murdoch's background values are listed in his report (Table 1, page 6) as 14 measured groundwater lead concentrations, collected in 2013 and compiled by the United States Geological Survey (USGS) under the National Water-Quality Assessment (NAWQA) Program. Dr. Murdoch's report refers to these measurements as "*background NAWQA samples*" (page 7, paragraph 2).

- The groundwater model presented in Dr. Murdoch's report is not developed in accordance with relevant technical standards, and fails to present an accurate and reliable representation of conditions at and near the Shaver property.
- As attested by Dr. Murdoch, the groundwater model results presented in his report do not support a linkage between the occurrences of elevated lead concentrations in the Shaver property and land applications by the Terra Defendants at the Kimrey Tract.
- In accordance with Dr. Murdoch's groundwater model results, even under the most over-conservative and unrealistic conditions, it would have been technically impossible for the reported materials applied by the Terra Defendants at the Kimrey Tract to have caused the alleged increases in groundwater lead concentrations in the Shaver well.

In summary, the conclusions of the analyses presented in Dr. Murdoch's report do not support a linkage or causality between any actions or inactions by the Terra Defendants and the occurrence of lead concentrations at or in the Shaver well.

4 I am continuing my review of the documents and data provided to me. The opinions presented in this report are based upon the data and information I reviewed at the time of the submission of this report. I reserve the right to modify or supplement my opinions based upon further review of information submitted or any additional data or information provided after the date of this report.

2 EXPERIENCE/QUALIFICATIONS/TRAINING/EDUCATION

5 I am an environmental scientist and professional engineer, a tenured university professor, and a consultant in environmental statistics, modeling, and data analysis. I hold a Ph.D. in Environmental Sciences (1983) and a S.M. in Environmental Engineering (1980), both from Harvard University, as well as a B.S. in Civil Engineering and B.A. in Economics from the University of California, Berkeley (1978). In 1990 I was awarded tenure and promoted to Associate Professorship at the Georgia Institute of Technology. I am the Founder/President of NewFields Companies, LLC (NewFields), which is an international partnership of environmental experts.

6 My groundwater research dates back to 1980, when I developed optimal geostatistical procedures for the analysis and monitoring of groundwater systems during my post-graduate studies. I subsequently developed geostatistical algorithms to analyze environmental spatial datasets within the framework of geographical information system (GIS) databases. In the course of my professional career, I have conducted research addressing a variety of environmental analytic issues. I have authored and co-authored numerous research publications, several invited reviews and book chapters, a compendium on applications of geostatistics in environmental and geotechnical engineering, a series of American Society for Testing and Material (ASTM) standard guides for application of geostatistics in environmental site investigations, and a four volume guidance document series on background data analysis for the United States Department of the Navy (DON).

7 I was the National Science Foundation visiting scientist at *Centre de Géostatistique, Ecole Nationale Supérieure des Mines de Paris*, France. I have been active in several professional societies and have served on the editorial boards of the American Geophysical Union (AGU)

Water Resources Research and the Association for Environmental Health and Sciences (AEHS) *Environmental Forensic* Journals. I was the chair of the American Society of Civil Engineers (ASCE) National Ground Water Hydrology Committee, as well as the chair of the ASCE Task Committee on Geostatistical Techniques in Geohydrology. I have been the expert member of the ASTM Geostatistics Standardization Committee and was responsible for the production of a series of ASTM standard guides on applications of geostatistics in environmental site investigations. I have assisted the U.S. Navy and the U.S. Army as an expert to review their installation restoration projects.

8 During the past three decades, I have led numerous investigations and conducted research in environmental statistics and geostatistics, deterministic and stochastic modeling of groundwater systems, and specifically, lead contamination in both soil and groundwater systems at Superfund (CERCLA) and Resource Conservation and Recovery Act (RCRA) sites throughout the United States, including Mountain Creek Lake Site, Dallas, TX; Mission Valley Site, San Diego, CA; Savannah River Site, SC; Factory Lane Site, Middlesex, NJ; NL Depew Site, NY; and Anniston Lead Site, AL. My recent technical efforts included assisting the United States National Oceanic and Atmospheric Administration (NOAA) by performing a leading role in sampling design and analysis of the comprehensive environmental data collected as part of the *Deepwater Horizon* Natural Resource Damage Assessment (NRDA).

9 A summary of my experience and education is provided in Section 8. My compensation and past witness information are provided in Sections 6 and 7, respectively.

3 INFORMATION RELIED UPON

10 In addition to my training, experience, and general knowledge of environmental and statistical principles, I have reviewed Dr. Murdoch's report, and relevant documents provided to me by Bondurant, Mixon & Elmore, LLP. Section 5 provides the list of provided documents and cited references.

4 OPINIONS

4.1 Opinion 1. Statistical tests presented in Dr. Murdoch's report are technically flawed, unreliable, and not conducted in accordance with accepted statistical practices.

11 Dr. Murdoch's report presents a series of statistical two-sample t-test results to compare three separate lead concertation datasets, listed in Tables 1, 3 and 4, respectively. As an initial matter, I note that Dr. Murdoch testified during his deposition on 11/14/2107 that he is "*not an expert statistician*" (Rough Draft, page 82, line 2). I am not surprised by this admission given the flaws in Dr. Murdoch's purported statistical tests.

12 Table 1 of Dr. Murdoch's report (page 6) lists 14 measured groundwater lead concentrations. These results are collected in 2013 and compiled by the United States Geological Survey (USGS) under the National Water-Quality Assessment (NAWQA) Program. Dr. Murdoch considers Table

1 data as the "*background NAWQA samples*" (page 7, paragraph 2). I refer to these measurements as "Dr. Murdoch's background values."[5]

13 In contrast, lead concentrations listed in Tables 3 and 4 (page 7 of Dr. Murdoch's report) are a mixture of lead concentrations associated with samples collected at the Shaver well and indoor water outlets within the Shaver property. These Shaver datasets contain eight (8) and three (3) lead concentrations, measured in 2016 and 2017, respectively.

14 Although unstated, the statistical tests are conducted to assess whether the measured lead concentrations in the Shaver property are significantly different from those measured in the background NAWQA samples, *i.e.* Dr. Murdoch's background values. Dr. Murdoch fails to identify the type of the selected two-sample test. The report (page 7, paragraph 3) simply states that: "*The analysis was done by assuming the variances of the datasets were unequal.*"[6] Dr. Murdoch seems to be unaware that the inequality of variances should not be assumed, but rather evaluated through appropriate tests, such as *Levene's test* (Levene, 1960). Levene's test is a common procedure to test the equality or inequality of variances. In fact, Dr. Murdoch admits during his deposition on 11/14/2017 that he is not even aware of the Levene's test (Rough Draft, page 80, line 23). By ignoring the appropriate tests to determine the inequality of variances, Dr. Murdoch has violated accepted statistical standards and practices. His presented statistical tests results, therefore, cannot be considered as reliable.

15 In order to perform a t-test where the variances of the datasets are unequal, one should use a t-test commonly known as *Welch's t-test* (Welch, 1947). Yet, Dr. Murdoch testified during his deposition on 11/14/2017 that he had not heard of Welch's t-test and did not know how to perform it (Rough Draft, page 86, line 17). While Dr. Murdoch did not know the name of the test, given his clear statement that he "assumed" inequality of variances, I suppose that what he utilized was, in effect, a Welch's t-test (I cannot know for certain because Dr. Murdoch failed to produce his calculations).

16 When a Welch's t-test is performed, it relies on a series of underlying assumptions, whose validity must be confirmed before its results can be considered as reliable. These assumptions include the normality of the investigated means, the representativeness and independence of measured values, and the inequality of variances.

17 Dr. Murdoch's report lacks any evidence about the confirmation of the validity of the underlying assumptions of his selected t-test. In fact, during his deposition on 11/14/2017, Dr. Murdoch admits that he did <u>not</u> perform any test to confirm the validity of the normality assumption (page 78, line 23), the inequality-of-variances assumption (page 80, line 12), or data-representativeness and independence assumptions (page 81, lines 15 and 20). Dr. Murdoch's failure to employ these

[5] Dr. Murdoch's report fails to provide any discussion on the representativeness and adequacy of his background values. In absence of such discussions, the listed values in Table 1 cannot be considered as appropriate measures of background conditions at or near the Shaver property.

[6] During his deposition on 11/14/2017, Dr. Murdoch seems to contradict his stated assumption of inequality-of-variances by saying that he assumed that "*the populations were independent*" and "*had similar variances and similar distribution*" (Rough Draft, page 77, line 24).

confirmatory tests is contrary to accepted statistical standards and practices, and renders his statistical analyses unreliable.

18 Dr. Murdoch's report also fails to acknowledge the fact that samples sizes as little as three measurements prevent any reliable confirmation of the validity of the underlying assumptions of the selected t-tests, including the normality and the inequality-of-variances assumptions. Expert statisticians in the environmental field would not rely on a sample size of three to reach definitive conclusions as Dr. Murdoch attempts to do in his report.

19 The representativeness of the investigated data is also highly questionable when considering that the background NAWQA dataset consists of randomly selected regional groundwater samples, while the other two datasets include mixtures of well and indoor water samples. That is, while Dr. Murdoch's background values represent groundwater concentrations only, he uses results from the Shaver property that include both groundwater samples and other samples derived from sources, such as the kitchen faucet and tub. Such haphazard mixtures are especially problematic when considering samples collected at the Shaver well contain lead concentrations that are different from those measured at the indoor water outlets of the Shaver property.

20 Dr. Murdoch's report lacks any test results demonstrating the statistical similarity of lead concentrations measured in the Shaver groundwater well samples and those measured in the Shaver indoor water samples. In absence of such test results, mixing of well and indoor data violates accepted statistical standards and principles.

21 In my opinion, even if we assume that the Dr. Murdoch's background values provide an appropriate background dataset (a point I disagree), the proper approach would have been to compare the NAWQA results only to those measured in the Shaver well. Such comparisons should not include samples from indoor locations whose lead concentrations may be affected or altered along the water conduit system.

22 Given the mixed nature of the Shaver datasets and in absence of reliable confirmation of the validity of the underlying Welch's t-test assumptions, none of the reported t-test results in Dr. Murdoch's report can be considered as statistically reliable.

4.2 Opinion 2. The results of statistical tests presented in Dr. Murdoch's report do not indicate that measured lead concentrations in the Shaver property are significantly different from Dr. Murdoch's background values.

23 Dr. Murdoch's report presents the resulting p-values of his t-tests in Table 5 (page 7). Although unstated in his report, Dr. Murdoch is using a *significance level*[7] of 10% or 0.1, corresponding to a confidence level of 90%. This is a peculiar choice given that a significance level of 5% is typically used in environmental and earth sciences, which corresponds to a 95% confidence level.

24 In my experience, environmental scientists and professionals most commonly use a significance level of 5% or less. For example, I performed a search for the recently published peer-reviewed academic environmental and geologic papers containing substantial discussions of statistical tests.[8] The search identified 140 abstracts. The overwhelming majority of these articles, *i.e.* 93% percent of the identified abstracts, use significance levels of 5% or less. Among these, more than 80% of articles use specifically the 5% significance level.

25 Ironically, Dr. Murdoch's own peer-reviewed published article, Kennedy *et al.* (2010), not only uses a 95% confidence level (5% significance level), but cites previous work that exclusively abide by the 5% significance level. These results raise serious doubts about Dr. Murdoch's decision to reduce the confidence level to 90%, which yields a significance level of 10%. In absence of any justification for such a decision, Dr. Murdoch's choice of a 10% significance level is simply arbitrary and unsubstantiated.

26 In fact, during his deposition on 11/14/2017, Dr. Murdoch testifies under oath that he selected his significance level ***after*** reviewing test results (Rough Draft, page 73, line 3). In a scientific hypothesis test, the investigator must define his or her confidence or significance level ***prior*** to analyzing the data. Selection of these critical decision levels after availability of results amounts to fabricating predetermined conclusions. Such a biased approach violates accepted statistical standards and principles, as well as principles of scientific evaluation. Dr. Murdoch's deposition highlights the fact that his selected significance level of 10% is not only arbitrary, but also biased.

27 Using the significance level of 5% that is typically used by environmental and earth science professionals, none of the reported p-values by Dr. Murdoch (Table 5, page 7) indicates a significant difference. In other words, Dr. Murdoch's background values are not significantly different from those lead concentrations measured in the Shaver property samples in either 2016 or 2017, *i.e.* lead concentrations measured in various samples collected within the Shaver property are statistically similar to Dr. Murdoch's background lead concentrations.

28 Using the more appropriate 5% significance level, none of Dr. Murdoch's reported p-values indicates a significant difference between the Shaver and his background NAWQA values. Dr.

[7] In statistical tests, the *significance level* is the criterion used for rejecting the null hypothesis. In this case, if the resulting p-value is less than or equal to the significance level, the datasets are said to be significantly different.
[8] The investigated database was *ProQuest Environmental Science Professional*, which covers the following major literature databases: Aqualine, Aquatic Science & Fisheries Abstracts (ASFA), Ecology Abstracts, Environmental Engineering Abstracts, Meteorological & Geoastrophysical Abstracts, Oceanic Abstracts, Pollution Abstracts, Risk Abstracts, Sustainability Science Abstracts, and Water Resources Abstracts.

Murdoch's statistical tests do not provide any evidence that the lead concentrations at the Shaver property are different from his background values.

4.3 Opinion 3. When Dr. Murdoch's datasets are modified to properly compare only groundwater samples to groundwater samples (as opposed to including samples from the sink and other similar locations within the Shaver property), the measured lead concentrations in the Shaver well in 2016 are not significantly different from Dr. Murdoch's background values.

29 As noted, Dr. Murdoch's Shaver 2016 and 2017 datasets are mixtures of samples collected at the well and various indoor locations. Given the fact that the background NAWQA data represent solely groundwater samples, Dr. Murdoch should have only used samples from the Shaver well in his statistical tests. These samples, listed in Dr. Murdoch's Table 3 (page 7), include Sample RE31003-001, collected on 5/27/2016, with a lead concentration of 10 ppb, and Sample AD80568, collected on 8/10/2016, with a lead concentration of 3.1 ppb. Applying Dr. Murdoch's selected test (Welch's t-test) to compare these values versus the background NAWQA samples results in a two-sided p-value of 0.433, indicating that the Shaver well lead concentrations are not significantly different from those measured in Dr. Murdoch's background NAWQA samples.[9]

30 According to the memorandum of February 21, 2017 of Bureau of Water, South Carolina Department of Health and Environmental Control (SCDHEC), the exceeding sample collected on 6/6/2016 was from a "shack." The only exceeding sample, collected on 6/6/2016 in Dr. Murdoch's list (Table 3, page 7) is Sample AD76802, with a lead concentration of 52 ppb. Despite the information provided in the cited SCDHEC memorandum, Bryan Shaver's deposition (page 20, line 12) suggests that this latter sample could have been collected at the Shaver well. Adding this sample to the list of Shaver well samples results in a two-sided p-value of 0.335 based on Dr. Murdoch's selected test (Welch's t-test). This p-value still indicates that the Shaver well lead concentrations are not significantly different from Dr. Murdoch's background values.[10]

31 The above results overwhelmingly indicate that lead concentrations measured in 2016 at the Shaver well are not significantly different from Dr. Murdoch's background values, meaning that any deviation between the Shaver well and background NAWQA concentrations can be attributed to chance or random variability.

[9] All statistical test computations presented in my report are conducted using IBM® SPSS® version 23.0.0.0 (https://www.ibm.com/analytics/data-science/predictive-analytics/spss-statistical-software).

[10] The reported p-value involves sample sizes as small as three. As noted, expert statisticians in the environmental field would not rely on a sample size of three to reach definitive conclusions.

4.4 Opinion 4: The groundwater model presented in Dr. Murdoch's report is not developed in accordance with relevant technical standards, and fails to present an accurate and reliable representation of conditions in and near the Shaver property.

32 Dr. Murdoch's report (page 9) presents a finite difference model to simulate groundwater flow and flow paths in and near the Shaver property. Although unstated, the objective of the groundwater modeling discussion appears to be the delineation of the capture zone of the Shaver well, and determining whether the capture zone contains any of the exploratory mine borings in the Kimrey Tract or any materials that may have entered into the exploratory mine borings either through the soil or through the surface.

33 Dr. Murdoch's three-dimensional model, presented on page 13 of his report (paragraph 1), consisting of 270 x 270 x 12 or 874,800 cells, covers a 24 square mile or 15,360 acre area surrounding the 36-acre[11] Shaver property. Contrary to established modeling standards and practices, Dr. Murdoch's modeling effort is not supported by any field measurement, or quantitative data collected at or near the Shaver property. Instead, as explained below, Dr. Murdoch reverts to guesses and broad regional information from locations far outside of his model coverage area to populate his elaborate groundwater model.

34 Dr. Murdoch on page 9 of his report (last paragraph) assumes that the underlying aquifer is unconfined and containing relatively permeable sand. Dr. Murdoch's report states that this important assumption is based on "*reviewing the hydrogeology of the site and considering pervious simulations conducted in the area*" (page 9, paragraph 4). The report, however, does not provide any evidence concerning the actual site-specific hydrogeological data, while failing to even identify "*previous simulations conducted in the area.*"[12] During his deposition on 11/14/2017, Dr. Murdoch admits that he did not have access to any site-specific geological information (Rough Draft, page 101, line 2), and that he made "*idealized assumptions*" because he did not have any site-specific subsurface information (Rough Draft, page 101, line 7). In absence of site-specific information, Dr. Murdoch's conceptual model based on "idealized assumptions" can only be considered as an unsubstantiated guess.

35 Dr. Murdoch's conceptual model based on "idealized assumptions" is set up such that the groundwater intercepted by the Shaver well originates exclusively from the shallow, local aquifer, whose recharge area includes the Kimrey Tract. This setup yields substantial downward/vertical flows from the recharge areas of the Kimrey Tract toward the Shaver well, as depicted in Figure 14 of Dr. Murdoch's report. Under Dr. Murdoch's "idealized assumptions", the recharge at the Kimrey Tract is the primary source of water supply to the Shaver well. Dr. Murdoch's model excludes the interception of any intermediate or regional groundwater by the Shaver well. Dr. Murdoch does not provide any site-specific information in support of the presence of such downward/vertical gradients at or near the Shaver well. Dr. Murdoch's model violates established

[11] Deposition of Bryan Shaver on 5/4/2017 (page 5, line 17).
[12] During his deposition on 11/14/2017, Dr. Murdoch states that the previous simulations refer to large-scale USGS models covering "*areas that were, I believe, varied in size, but they would be the size of the state of South Carolina coastal plain. They're the one that includes -- it's the southeastern U.S, so South Carolina, North Carolina, and even extending into Georgia, Virginia*" (Rough Draft, page 90, line 25).

modeling standards and practices by ignoring the need for site-specific information. Such a model cannot be considered as a reliable representation of conditions at or near the Shaver well.

36 The absence of site-specific hydrogeologic data becomes even more problematic, when Dr. Murdoch admits that "*the location of the clay beds is difficult to anticipate*" (page 9, paragraph 4). This uncertainty is especially troubling when considering that the extent and thickness of clay beds have profound impacts on the direction and magnitude of groundwater flow. For example, a near-surface clay bed north of the Shaver property can substantially impede the flow of recharged water from the Kimrey Tract to the Shaver well. Dr. Murdoch does not provide any evidence on how he has incorporated his uncertainties regarding clay beds into his groundwater model. Dr. Murdoch's model violates established groundwater modeling standards and practices by ignoring the need for incorporation of uncertainties in the modeling process.[13] Such a model, based on "idealized assumptions", cannot be considered as a reliable representation of the groundwater flow at or near the Shaver property.

37 Presence of clay layers have been confirmed in a number of soil samples collected for sieve analysis from the Kimrey Tract.[14] Dr. Murdoch's own support documents include boring logs from locations in Wallace, SC that indicate highly variable layers containing clay with thicknesses as high as 30 feet.[15] This local and regional information clearly indicates that a reliable groundwater model of the Shaver property and its vicinity requires site-specific data about clay beds. In absence of such site-specific information, Dr. Murdoch's model cannot be considered as a reliable representation of the groundwater flow at or near the Shaver property.

38 In Dr. Murdoch's model, recharge rates are critical input variables, because they form the basis of his model calibration. Dr. Murdoch's report states (page 13, paragraph 2): "*The model was calibrated by assuming the recharge was accurate so the hydraulic conductivity was adjusted to represent the conditions in the field area.*" This statement implies that the accuracy of recharge rates is the key to the reliability of Dr. Murdoch's calibrated model. The question that immediately arises is: how accurate are Dr. Murdoch's recharge rates?

39 Dr. Murdoch does not present any site-specific measurements, such as rainfall data, in support of his "assumed accurate" recharge rates. In fact, during his deposition on 11/14/2017, Dr. Murdoch admits that he did not even considered the local rainfall data during the preparation of his expert report (Rough Draft, page 8, line 8). Instead, Dr. Murdoch states on page 9 of his report (last paragraph): "*I <u>assumed</u> the annual recharge was 24 inches on the flat-lying upland areas that are regularly plowed, 12 inches on the upland wooded areas and 6 inches on the slopes*" (emphasis added).

40 Dr. Murdoch's "assumed accurate" recharge values are based on a few regional references. Among these references, he gives special emphasis to Haven (2003), cited on page 9, last

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[13] In fact, during his deposition on 11/14/2017, when asked about how he has incorporated his uncertainties about the clay beds, Dr. Murdoch responded with an irrelevant statement: "*I assumed that the properties were uniform and isotropic, and that was I think a reasonable assumption based on the information that was available*" (Rough Draft, page 113, line 22).

[14] See pdf file "Sieve Analysis Worksheets."

[15] See page 25 of the pdf file "MURDOCH 6 through 8."

paragraph, with a reproduced figure of estimated groundwater recharge rates for North Carolina (Figure 5, page 12). Dr. Murdoch's report states: "*Haven (2003) indicates the recharge is between 5 inches and 25 inches, with higher values on flat lying uplands and lower values on slopes.*" As the zoomed portion of Figure 5 indicates, in the North Carolina county nearest to the Shaver property, annual recharge is between 5 centimeters to 25 centimeters (not 5 inches to 25 inches). The unit discrepancy between inches and centimeters suggests that Dr. Murdoch's "assumed accurate" recharge rates can be off by 250%.[16]

41 Ironically, during his deposition on 11/14/2017, Dr. Murdoch admits that he did not measure recharge rates at or near the Shaver property (Rough Draft, page 127, line 22), did not have any data about recharge rates at or near the Shaver property (Rough Draft, page 128, line 3), and assumed the recharge rates "*not based on information at the* [Shaver] *property*" (Rough Draft, page 128, line 23). Given Dr. Murdoch's lack of information about recharge rates at or near the Shaver property and in absence of any site-specific data regarding his "assumed accurate" recharge rates, Dr. Murdoch's groundwater model cannot be considered as a reliably calibrated representation of recharge conditions at or near the Shaver property.

42 Given the critical role of recharge rates in his modeling work, Dr. Murdoch's groundwater model violates accepted groundwater standards and practices by ignoring the need for site-specific recharge data. Such a model cannot be considered as a reliable and calibrated representation of the groundwater flow at or near the Shaver property.

43 Dr. Murdoch's model also contains constant head boundary cells to represent the streams (page 13, paragraph 1). The report, however, lacks any information about the source or the magnitude of the assigned constant heads. During his deposition on 11/14/2017, Dr. Murdoch claims that his constant heads are initially based on the USGS digital elevation maps (Rough Draft, page 131, line 3). However, during subsequent questioning, he reveals that those assigned constant heads based on USGS digital elevation maps were "adjusted" during the "calibration" process (Rough Draft, page 131, line 16). Dr. Murdoch also admits that during the calibration process, he "moved" the location of the streams (Rough Draft, page 132, line 5). Dr. Murdoch's report does not provide any information on how uncertainties associated with the location and elevation of streams are incorporated in his model. Dr. Murdoch's groundwater model violates established groundwater modeling standards and practices by ignoring the need to incorporate uncertainties associated with constant head boundary cells into the modeling process. Such a model cannot be considered as a reliable representation of stream conditions at or near the Shaver property.

44 The focal point of Dr. Murdoch's model is the Shaver well. Despite the importance of this well, Dr. Murdoch admitted during his deposition on 11/14/2017, that he did not have access to complete or reliable information regarding the screen depth of the Shaver well (Rough Draft, page 98, line 10). He also admits that he did not incorporate the uncertainties regarding the

[16] During his deposition on 11/14/2017, Dr. Murdoch refers to Giese *et al.* (1997) as one of the sources of his "assumed" recharge rates (page 125, line 12). Giese *et al.* (1997) contains a map (Figure 24, page 43) that depicts recharge rates in portion of North Carolina. In this map, the nearest county to the Shaver property appears to have a uniform recharge rate of 20 inches per year. Contrary to Dr. Murdoch's statements, the suggested recharge rate in this document neither corresponds to recharge values assumed by Dr. Murdoch, nor suggests recharge variations among various landscapes.

Shaver well screen interval into his model (Rough Draft, page 98, line 19). Absence of complete and reliable information about specific features of the Shaver well raises serious doubt about the reliability of Dr. Murdoch's model.

45 Dr. Murdoch explains that the lateral and vertical hydraulic conductivities of his 874,800 model cells are determined through a "calibration" process. Although not stated clearly, prior to this so-called "calibration," Dr. Murdoch seems to assume that the vertical hydraulic conductivity in each cell is one-order of magnitude less than its lateral hydraulic conductivity, and the eastern zone of his model, containing the Shaver property, has hydraulic conductivities that are one order of magnitude less than those in the western zone of his model. In addition, Dr. Murdoch's report is completely silent on the initial hydraulic values that had been assigned to his 874,800 cells before being "adjusted" during the calibration process.[17] All of Dr. Murdoch's pre-calibration assumptions are made without any supporting site-specific measurements. Without site-specific measurements, such broad assumptions cannot be considered as either reliable, or accurate.

46 Dr. Murdoch's calibration process, which is poorly described on page 13 of his report, seems to be based on generating hydraulic heads below ground and within the depth intervals of the Kimrey Tract exploratory mine borings. Other than unspecific statements like: "*It was assumed that the water in the borings represented the height of the water table*," no specific information is provided. The cited sentence is followed by a vague statement: "*The model was calibrated to match this observation*." To the best of my knowledge, measured water depths in the exploratory mine borings are not available.[18] So what is the "observation" that forms the basis of Dr. Murdoch's calibration? In absence of quantitative site-specific proofs, Dr. Murdoch's groundwater model cannot be considered as either reliably, or accurately calibrated.

47 Ironically, Figure 16 of Dr. Murdoch's report (page 25) indicates that his "calibrated" hydraulic head does <u>not</u> encompass the depth interval covered by the closest exploratory mine boring to the Shaver property, identified as KP-28-16. Such a result contradicts his earlier statement on page 13 of his report about "*the water in the borings represented the height of the water table*," and raises serious doubts about the reliability of his calibrated model.

48 United States Environmental Protection Agency (USEPA, 2009) document, titled "*Guidance on the Development, Evaluation, and Application of Environmental Models*," provides general rules for developing a reliable groundwater model. This guidance document (USEPA, 2009, page vii, last paragraph) "*recommends that model developers and users: (a) subject their model to credible, objective peer review; (b) assess the quality of the data they use; (c) corroborate their model by evaluating the degree to which it corresponds to the system being modeled; and (d) perform sensitivity and uncertainty analyses*."

49 Dr. Murdoch's report does not provide any evidence regarding a credible, objective peer review of his groundwater model. The report lacks even the most basic forms of data quality assessment.

[17] During his deposition on 11/14/2017, Dr. Murdoch admits that he could not recall the initial assigned hydraulic conductivity values (Rough Draft, page 137, line 13). He also added that he is not even sure that those initial values are available anymore (Rough Draft, page 137, line 15).

[18] During his deposition on 11/14/2017, Dr. Murdoch testified that he measured the water level at the Shaver well during his site visit that occurred after the submission of his expert report (Rough Draft, page 11, line 22).

The report also fails to corroborate the model by evaluating the degree to which it corresponds to the system being modeled. Last but not least, the report is devoid of any sensitivity and uncertainty analyses. Dr. Murdoch's groundwater model violates established groundwater modeling standards by ignoring the above cited general rules of modeling. Such a model cannot be considered as either reliable, or accurate representation of conditions at or near the Shaver property.

4.5 Opinion 5: As attested by Dr. Murdoch, the groundwater model results presented in his report do not support a linkage between the occurrences of elevated lead concentrations in the Shaver property and land applications by the Terra Defendants at the Kimrey Tract.

50 As noted, although unstated, the objective of Dr. Murdoch's groundwater modeling effort appears to be the delineation of the capture zone of the Shaver well, and determining whether the capture zone contains any of the exploratory mine borings in the Kimrey Tract or any materials that may have entered these borings through the soil or surface.

51 During his deposition on 11/14/2017, Dr. Murdoch's admits that that he has no evidence that any action or inaction by the Terra Defendants at Kimrey Tract (Rough Draft, page 30, line 12) have caused the alleged increases in lead groundwater concentration in the Shaver well.

52 Dr. Murdoch's testimony is consistent with the results presented in his report, which delineates the capture zone of the Shaver well in Figures 13 and 15. These figures indicate that the capture zone of the Shaver well covers a very small portion of the Kimrey Tract, and is disconnected both laterally and vertically[19] from any of the exploratory mine borings in the Kimrey Tract. Such results refute the presence of a rapid pathway from the Kimrey Tract to the Shaver well via the exploratory mine borings. As stated in Dr. Murdoch's report (page 9, paragraph 2) and displayed in Figure 1: "*Contaminants that enter the groundwater system outside the capture zone of the* [Shaver] *well will flow through the groundwater system and* ***ultimately discharge at a location other than the*** **[Shaver]** ***well***" (emphasis added).

[19] See Dr. Murdoch's report, Figure 16, page 25 for the vertical disconnection of the exploratory mine borings and the capture zone.

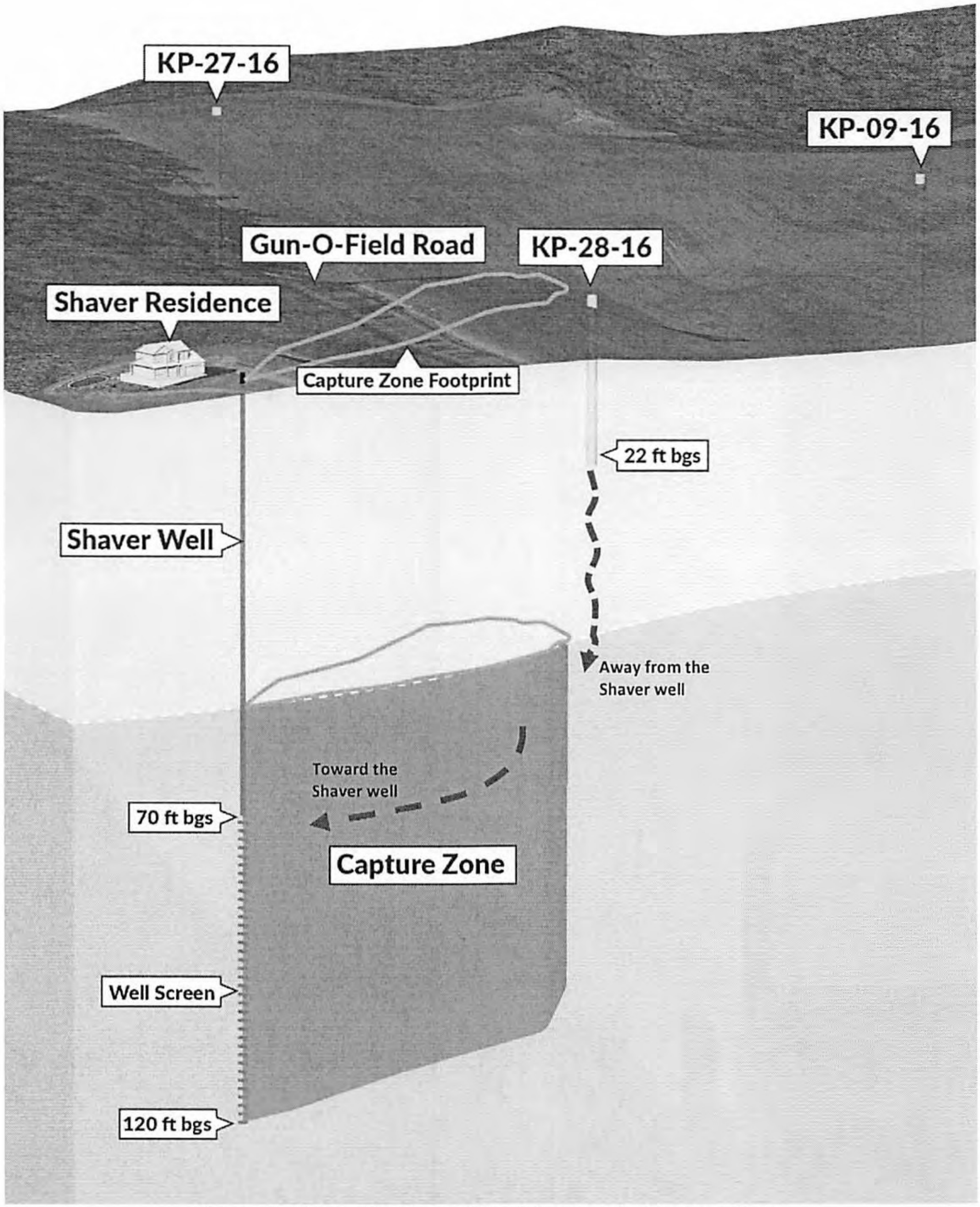

Figure 1. Reproduction of Dr. Murdoch's Capture Zone
(ft bgs = feet below ground surface)

53 The above conclusion is further supported by Dr. Murdoch's model results, which indicate that observing an impact in the Shaver well within few weeks of land applications in the Kimrey Tract is hydrogologically impossible. To demonstrate this point, I calculated the travel time of a water particle from the nearest location within the capture zone on the Kimrey Tract to the Shaver well.

54 Based on the results provided by Dr. Murdoch, I first computed the lateral seepage velocity, which is defined as the product of hydraulic conductivity and gradient divided by the effective porosity:

- Hydraulic Conductivity: Dr. Murdoch's report identifies the "calibrated" lateral hydraulic conductivity assigned to cells at or near the Shaver property as 2.5×10^{-6} m/s (page 14, paragraph 2).
- Hydraulic Gradient: Based on Dr. Murdoch's groundwater model, the hydraulic head in the nearest Kimrey Tract cell immediately upgradient of the Shaver well is 78.4 meters above mean sea level (m msl).[20] The Shaver well, which is located about 265 feet or 80.8 m downgradient from this cell, has an average predicted hydraulic head of 75.99 m msl. These values translate into a hydraulic gradient of 0.0294 m/m.
- Effective Porosity: Given Dr. Murdoch's assumption about the "*relatively permeable sand*" content of the aquifer (page 9, last paragraph), I used an effective porosity of 37.5% – a conservative value based on mid-range of porosity values of sand aquifers (Freeze and Cherry, 1979, page 37).

55 The above values yields a lateral seepage velocity of 1.99×10^{-7} m/s. At this lateral seepage velocity, the travel time from the nearest upgradient location within the Kimrey Track to the Shaver well is calculated by dividing the distance of 80.8 m by the seepage velocity. The calculated travel time according to Dr. Murdoch's groundwater model is 12.9 years.

56 So even if one assumes that the material applied at the Kimrey Track somehow reached the groundwater instantaneously (a highly unrealistic assumption), according to Dr. Murdoch's results, it would take more than 12 years for this material to reach the Shaver well. Such material do not include those that may have entered the exploratory mine borings via the soil or surface. According to Dr. Murdoch's model results, these latter material, if occurring at all, would enter the groundwater outside of the capture zone of the Shaver well and discharge at locations other than the Shaver well.

57 In the above calculation, for the sake of conservatism, the vertical travel time along the unsaturated soil and the saturated aquifer is ignored and set to zero. Inclusion of the vertical travel time would increase the travel time far beyond the above computed duration. This confirms that based on Dr. Murdoch's results, observing an impact in the Shaver well within few weeks of land applications in the Kimrey Tract is hydrogeologically impossible. These findings clearly indicate that Dr. Murdoch's groundwater model results not only disprove, but refute the presence of a linkage between the occurrence of lead concentrations in the Shaver property and land applications at the Kimrey Tract.

[20] For this purpose, I used groundwater model input files provided by Dr. Murdoch to run his model using *GroundwaterVista* software, Version 6.9.6 (www.groundwatermodels.com/).

4.6 Opinion 6: In accordance with Dr. Murdoch's groundwater model results, even under the most over-conservative and unrealistic conditions, it would have been technically impossible for the reported materials applied by the Terra Defendants at the Kimrey Tract to have caused the alleged increases in groundwater lead concentrations in the Shaver well.

58 I reviewed the land application data provided in TRS_Shaver000344. The total reported lead application rate is 0.0642 lbs per acre. The Kimrey Tract portion of the capture zone delineated in Dr. Murdoch's Figure 15 is approximately equal to 0.6 acres. This means that total amount of applied lead within the capture zone of the Shaver well was only 0.039 lbs.

59 I then assumed a highly over-conservative and unrealistic transport scenario consisting of: (a) zero soil adsorption of infiltrated lead; (b) instantaneous migration of all applied lead to groundwater; (c) instantaneous impact of the entire capture zone of 1.24 acres; and (d) confinement of the migrated lead within a 50-foot layer of the aquifer leading to the screen of the Shaver well. In layman's term, I assumed that all lead that was applied during Terra Defendants' operations reached the groundwater instantaneously and flowed into the Shaver well.

60 Even under this highly over-conservative and unrealistic transport scenario, the resulting lead concentration at the Shaver well would be less than 1 ppb. This finding clearly indicates that under Dr. Murdoch's model, it would have been technically impossible for the reported materials applied by the Terra Defendants at the Kimrey Tract to have caused the alleged increases in groundwater lead concentrations in the Shaver well.

61 In conclusion, based on my review of the documents provided to me in this case, results of Dr. Murdoch's statistical tests and groundwater model indicate that none of actions or inactions by the Terra Defendant in the Kimrey Tract could have caused the alleged increase in lead concentrations at the Shaver well or property.

5 REFERENCES

The documents that I received and reviewed in this case are listed in Table 1. This table is followed by the list of additional cited references.

Table 1. List of Documents

Doc	Title	Content	Date
1	Murdoch expert report.pdf	Dr. Murdoch's export report	Undated
2	MURDOCH 1 through 5.pdf	Appendix 1 through 5 of Dr. Murdoch's export report	Undated
3	MURDOCH 6 through 8.pdf	Appendix 6 through 8 of Dr. Murdoch's export report	Undated
4	MURDOCH CORRESPONDENCE.pdf	Email correspondence between Dr. Murdoch and attorneys at Ingram Law Firm	5/30/2017 – 10/3/2017
5	MURDOCH,LARRY,11,14,17.ROUGHDRAFT.txt	Rough Draft of Dr. Murdoch's deposition	11/14/2017
6	04 Terra Darling RFP1.pdf	Map of mine site plan for Kimrey and Hatcher Tracts; Map of reclamation plan for Kimrey and Hatcher Tracts; Aerial image showing the distance between the Shaver well and the closest exploratory mine boring.	12/5/1997; 12/5/1997; 2017
7	024 - 2017-05-07 Amended Complaint.pdf	Amended complaint from attorneys for plaintiffs	5/7/2017
8	IMAG01359.jpg	Picture showing the cloudy water sample	Unknown
9	IMAG01394.jpg	Picture of one boring hole with water in it	Unknown
10	Kimrey Tract Soil Sampling Location Map.pdf	Kimrey tract soil sampling location map	11/2/2017
11	Kimrey Tract Soil Sampling Report.pdf	Kimrey tract soil sampling lab report	11/3/2017
12	Pages from ASG 00001 - 00290.pdf	Map of Kimrey property and Quinn Property	2/21/2017
13	Pages from ASG 00001 - 00290-2.pdf	Picture of drilling equipment	Unknown
14	Pages from DHECFOIA000001.pdf	Findings about water samples collected at Shaver's property by SC Department of Health and Environmental Control	2/21/2017
15	Pages from TRS_SHAVER000330.pdf	Field report from Terra Renewal documenting chemical loading rates from 4/19/2016 to 5/10/2016	12/31/2016
16	SC_ShaverDrawing.pdf	Conceptual cross section of injection furrow crossing bore hole	Unknown
17	Shaver, Brian - Mini.pdf	Bryan Shaver's deposition	5/4/2017
18	Shaver, Melissa - Mini.pdf	Melissa Shaver's deposition	5/5/2017
19	Sieve Analysis Worksheets.pdf	Sieve analysis worksheets for borings at Kimrey tract sampled from 3/8/2016 to 3/22/2016	2016
20	Terra Renewal_Shaver_Borings&Well_Aerial.jpg	Aerial image of the approximate location of relevant borings in relation to Shaver Well on USGS topography	2017
21	TRS_SHAVER000001.pdf	Picture of one boring hole	Unknown
22	TRS_SHAVER000002.pdf	Picture of farm land with one boring hole and tire/equipment tracks	Unknown
23	TRS_SHAVER000003.pdf	Picture of one boring hole	Unknown
24	TRS_SHAVER000004.pdf	Picture of farm land with one boring hole and tire/equipment tracks	Unknown
25	TRS_SHAVER000005.pdf	Picture of farm land with one boring hole and tire/equipment tracks	Unknown
26	TRS_SHAVER001575.pdf	Application rate and vehicle speed chart	Unknown
27	MODFLOW GMS and Native Files	Dr. Murdoch's groundwater model input/output files (Generated on 11/19/2017)	11/19/2017

Freeze, R.A., Cherry, J.A. 1979. *Groundwater*. Prentice-Hall, Inc.

Giese G.L., Eimers J.L., and Coble R.W. 1997. *Simulation of Ground-Water Flow in the Coastal Plain Aquifer System of North Carolina*. U.S. Geological Survey Professional Paper 1404-M. https://pubs.usgs.gov/pp/1404m/report.pdf

Haven W.T. 2003. *Introduction to the North Carolina Groundwater Recharge Map*. Groundwater Circular Number 19. North Carolina Department of Environmental and Natural Resources. Division of Water Quality. http://digital.ncdcr.gov/cdm/ref/collection/p16062coll9/id/243434

Kennedy C.D., Murdoch L.C., Genereux D.P., Corbett D.R., Stone K., Pham P., and Mitasova H. 2010. Comparison of Darcian Flux Calculations and Seepage Meter Measurements in a Sandy Streambed in North Carolina, United States. *Water Resources Research* 46(9).

Levene, Howard (1960). "Robust tests for equality of variances". In Olkin, I. *et al. Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling*. Stanford University Press. pp. 278–292.

United States Environmental Protection Agency (USEPA). 2009. *Guidance on the Development, Evaluation, and Application of Environmental Models*. EPA/100/K-09/003. Office of the Science Advisor, Council for Regulatory Environmental Modeling, Washington, DC.

Welch B.L. 1947. The Generalization of 'Student's' Problem when Several Different Population Variances are Involved. *Biometrika* 34(1/2): 28-35.

6 COMPENSATION

Fees for my services including review of documentation and production of reports are billed by NewFields Companies, LLC, at an hourly compensation rate of $300. My compensation is in no way connected to or dependent on the conclusions that I have reached in this case.

7 OTHER WITNESS INFORMATION

In the last four years, I have provided testimony in the following cases:

- Expert for Defendants in "U.S. Home Corporation and Lennar Corporation v. Settlers Crossing, LLC, Washington Park Estates, LLC, Bevard Development Company, Steven B. Sandler, and iStar Financial, Inc." in the United States District Court, District of Maryland, Civil Action No.: 8:08-cv-01863-DKC (D. Md.). 2014 (Report, Deposition and Testimony).
- Expert for Claimants in "Perenco Ecuador Limited vs. Republic of Ecuador," ICSID Case No. ARB/08/6, International Center for Settlement of Investment Disputes, The Hague, 2013 (Report and Testimony).
- Expert for Claimants in "Burlington Resources Inc. vs. Republic of Ecuador," ICSID Case No. ARB/08/5, International Center for Settlement of Investment Disputes, Paris, 2014 (Report and Testimony).
- Expert for Defendants in Civil Action No.: 5:08-CV-00460-FL "Duke Energy Progress v. 3M Company, et al.," and Civil Action No.: 5:08-CV-00463-FL "Consolidation Coal Company v. 3M Company, et al." in The United States District Court for the Eastern District of North Carolina Western Division, 2014 (Report and Deposition).
- Expert for Defendants in "NL Industries, Inc. v. ACF Industries, et al.," Docket No. 10-cv-00089 (EAW)(HBS), United States District Court, Western District of New York, 2015 (Reports and Deposition).
- Support Expert for Defendants in Case No. CIV-13-1157-M "Helen Briggs et al. v. Freeport-McMoran Copper & Gold Co., Freeport-McMoran 10 Corporation f/k/a Phelps Dodge Corporation; Cyprus Amax Minerals Co.; and Blackwell Zinc Co., Inc." in the United States District Court for the Western District of Oklahoma, 2015 (Rebuttal Declaration).
- Expert for Plaintiff in "City of Los Angeles v. BAE Systems San Diego Ship Repair, Inc." Case No. 13-CV-8810 CBM(AGRx), United States District Court, Central District of California, 2016. (Rebuttal Report and Deposition)

- Expert for Claimants in "Nokia Technologies Ltd (Claimant) v. LG Electronics, Inc. (Respondent)," International Chamber of Commerce Case No. 22326/EMT/GR, 2016. (Reports)

8 CURRICULUM VITAE

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EDUCATIONAL BACKGROUND

Ph.D.	1983	Harvard University	Environmental Sciences
S.M.	1980	Harvard University	Engineering
B.A.	1978	University of California, Berkeley	Economics
B.S.	1978	University of California, Berkeley	Civil Engineering

PROFESSIONAL EXPERIENCE

President	NewFields Companies, LLC	1995 - Present
Editorial Board Member	*Environmental Forensics* Association for Environmental Health and Sciences	2003 - Present
Adjunct Professor	School of Civil and Environmental Engineering Georgia Institute of Technology	1996 - 2004
Associate Professor	School of Civil and Environmental Engineering Georgia Institute of Technology	1990 - 1996
Senior Consultant	Dames & Moore Atlanta, GA	1990 - 1995
Chairman	National Ground Water Hydrology Committee, Hydraulics Division, American Society of Civil Engineers	1991 - 1992
Expert Member	ASTM/EPA/USGS/DOD Geostatistics Standardization Committee	1991 - 1998
Associate Editor	*Water Resources Research* American Geophysical Union	1989 - 1994
Assistant Professor	School of Civil Engineering Georgia Institute of Technology	1983 - 1990
Chairman	Task Committee on Geostatistical Techniques in Geohydrology, American Society of Civil Engineers	1987 - 1989
National Science Foundation Visiting Scientist	*Centre de Géostatistique, Ecole Nationale Supérieure des Mines de Paris*, France	1987 - 1988

PROFESSIONAL REGISTRATION

Licensed Professional Engineer — Georgia (Registration Number 19369)

CURRENT FIELD OF INTEREST

Geostatistics
Environmental Statistics
Geostatistical and Stochastic Hydrology
Decision Analysis
Groundwater and Surface Hydrology

HONORS AND AWARDS

Tau Beta Pi (National Engineering Honor Society)	1977
Chi Epsilon (Civil Engineering Honor Society)	1978
Phi Beta Kappa (National Honor Society for Students in Social Sciences)	1978
Watson Award, Division of Applied Sciences, Harvard University	1979-82
Sigma Chi (Scientific Research Society)	1987
1990 Who's Who (Rising Young Americans)	1990
ASCE Task Committee Excellence Award, Hydraulics Division (S. Rouhani, Chairman of ASCE Task Committee on Geostatistical Techniques in Geohydrology)	1991
Dictionary of International Biography - 22nd Edition	1992
Two Thousand Notable American Men, First Edition	1992
Who's Who in America	1995-Present

REPRESENTATIVE PROJECT EXPERIENCE

Government Sector Sample Projects

NOAA Assessment of Deepwater Horizon MC252 Oil Impacts – Principal investigator for development of statistical sampling designs and conducting statistical analyses for various shoreline technical working groups as part of NRDA evaluation.

United Nations Compensation Commission Expert Assessment – Extensive sediment and soil data provided associated with the environmental damages from post-1991 Kuwait conflict were statistically and geostatistically analyzed. These analyses were conducted as part of the UNCC technical review of submitted claims.

US EPA Project on Multivariate Geostatistical Trend Detection and Network Design for Acid Deposition Data– Principal investigator for development of a multivariate geostatistical technique for trend detection in acid deposition data and spatial evaluation of current national network, known as NAPD/NTN.

US EPA Project on Statistical Source Contamination Identification, Coleman-Evans Superfund Site, Whitehouse, FL – On behalf of EPA, extensive historical soil data were analyzed in order to determine the extent of ambient versus site-related dioxins.

US EPA Project on Statistical Source Contamination Identification, ACW Superfund Site, Pensacola, FL – On behalf of EPA, extensive historical soil data were analyzed in order to determine the extent of ambient versus site-related dioxins.

US EPA Guidance for Soil Cleanup Strategies – Principal author on geostatistical procedures for optimal soil cleanup delineation.

US Navy CURT (Clean Up Review Team) – Technical lead on strategic review of US Navy environmental restoration projects worldwide. In this role Dr. Rouhani assisted US Navy to review more than 750 projects and identify more than $100 million in cost-avoidance.

US Navy Mole Pier, San Diego Naval Station, CA – Project director for the data evaluation and analysis of the anticipated $40 million dollar clean-up project.

US Navy Allen Harbor Landfill, North Kingstown, RI – Project director for updating superfund remedy selection. The original cap remedy cost was estimated at $14 million.

US Navy, Cecil Field, Naval Air Station Jacksonville, FL – Project director for the geostatistical analysis of lead soil data at a former firing range. This project was later selected by the US EPA as a case study for an upcoming guidance document on optimal soil remedy selection at CERCLA sites.

US Navy, Mountain Creek Lake, NWIRP Dallas, TX – Principal investigator for the sediment background analysis. This innovative study led to an expedited approval of sediment delineation, while avoiding a potentially expensive and time-consuming ecological risk assessment.

US Navy RITS Lectures and CECOS Classes – Principal lecturer at US Navy Remediation Innovative Technology Seminar (RITS), as well as a regular lecturer at CECOS courses on Environmental Background Analysis, Navy Environmental Restoration Program, and Environmental Sampling Design and Data Quality Assessment.

US Department of Energy Project on Application of Geostatistical Methods to Savannah River Site Environmental and Geotechnical Investigation, SC – Principal investigator for development and application of advanced procedures for evaluation of the adequacy of groundwater quality data at a waste site, as well as development of geostatistical estimation/simulation procedure in support of seismic modeling of the site.

South Florida Water Management District, US Sugar Land Acquisition, FL – Developed and negotiated the approval of statistical procedures for due diligent sampling and analysis process, conducted the statistical analysis of due diligent soil samples, developed confirmatory sampling and analysis process, and participated in technical discussions and negotiations.

St. Johns River Water Management District Minimum Flow Determination, FL – Developed an innovative combined hydrodynamic and statistical approach to establish minimum flow levels for Blue Spring based on protection of manatees winter refuge criteria.

St. Johns River Water Management District Geostatistical Peer Review, FL – Lead technical reviewer for numerous projects at SJRWMD, including optimization of groundwater monitoring networks, mapping of potentiometric surfaces, groundwater flow modeling, assessment of seagrass monitoring protocols, Lake Apopka soil data analysis, and time series analysis of groundwater and lake monitoring data.

South Florida Water Management District Lower West Coast Potentiometric Mapping, FL – Technical lead on statistical and geostatistical analysis of available seasonal, multi-layer groundwater elevation data for Lower West Coast potentiometric Mapping.

<u>Private Sector Sample Projects</u>

Anniston Lead Site, Anniston, AL – Lead negotiation, cleanup, and sampling efforts at Anniston Lead Site, Alabama. These efforts included statistical and geostatistical analyses of soil lead and PCB data in order to verify the extents of zones of investigations.

Alabama Wood Treaters Site, Mobile, AL – Principal investigator concerning a legal dispute on cost recovery. This project involved analysis of an extensive list of historical documents and aerial photographs.

RFI Investigation, Middlesex, NJ – Principal investigator for soil arsenic background data analysis. This project involved compilation and analysis of large historical datasets for determining arsenic background concentrations.

Geostatistical Source Impact Delineation, Mission Valley, San Diego, CA – Extensive BTEX, MTBE groundwater database was geostatistically analyzed in order to define the extent of site-related plumes.

Groundwater statistical optimization, Athens, GA – Assessment of soil and groundwater at manufacturing facility in Athens, Georgia. Geostatistics was used to (1) characterize the groundwater contamination in a three-dimensional framework, and (2) identify areas which Figure either data gaps, or potentially elevated contaminations. Geostatistically produced kriged and quantile maps were used to characterize the site contamination, as well as identify location for subsequent sampling activities.

Statistical Risk Evaluation, Detroit, MI – Principal investigator for risk assessment study of a major development site. Geostatistics were used to estimate surface soil block contamination, evaluate the adequacy of the existing surficial measurements, and design an information-efficient deep soil sampling plan.

Soil Characterization Planning and Optimization, Charleston, SC – An innovative phased geostatistical sampling plan was developed to characterize soil and groundwater contamination at a RCRA industrial site in South Carolina.

Groundwater Transport Modeling for Remedial Evaluation, Atlanta, GA – Determined the effectiveness of a proposed list of groundwater remedial alternatives at a CERCLA site through the use of U.S. Geological Survey groundwater flow/transport model, MOC-2D. The results of the model provided a realistic assessment of long-term potential efficiency of the various pump-and-treat alternatives.

Risk Evaluation of Contaminated Sites in Michigan – Existing soil data from an abandoned industrial site in Michigan were geostatistically analyzed to perform two tasks: (1) to characterize the site contamination in a multi-layer framework, and (2) identify areas which Figure either data gaps, or potentially elevated contaminations.

Spatial Statistical Assessment, Baton Rouge, LA – Performed an extensive soil and groundwater analysis at a CERCLA site in Baton Rouge, Louisiana. Site was geostatistically analyzed in order to perform four major tasks: (1) to characterize three-dimensional soil contamination mapping, (2) to calculate block-area groundwater contamination levels, (3) to produce sampling plans for subsequent measurements, and (4) to provide the most accurate information on the spatial distribution of Analytes of the groundwater flow/transport model of the site.

Data Analysis at a Former Refinery, Peñuellas, Puerto Rico – Principal investigator for the compilation and analysis of available soil and groundwater, as part of a RCRA Facility Investigation.

Statistical Assessment of Migration Potential, Memphis, TN – Principal investigator for the geostatistical analysis of existing data on the thickness of a critical near-surface aquitard to determine zones of potential leakage to the lower aquifer.

GEORGIA TECH REPRESENTATIVE STATISTICAL RESEARCH EXPERIENCE

Title:	Optimal Sampling of Stochastic Processes
Sponsor:	National Science Foundation
Duration:	(6/1/85 to 10/30/87)
Subject:	In this project, Dr. Rouhani developed optimal sampling and monitoring techniques for ground water quantity and quality investigations, based on advanced geostatistical procedures. It was shown that using such techniques can yield economically efficient sampling plans.

Title:	Optimal Schemes for Ground Water Quality Monitoring in the Shallow Aquifer, Dougherty Plain, Southwestern Georgia
Sponsor:	U.S. Geological Survey
Duration:	(4/1/86 to 3/31/87)
Subject:	In this project, Dr. Rouhani developed a flexible geostatistical procedure for planning a ground water quality monitoring network in Dougherty Plain, Georgia. The proposed network acts as a warning system for the protection of the Floridian Aquifer system which is a major source of water in south Georgia and Florida.

Title:	Advanced Geostatistical Studies at the Centre de Geostatistique, Ecole des Mines de Paris.
Sponsor:	National Science Foundation
Duration:	(9/1/87 - 2/18/89).
Subject:	Through this project Dr. Rouhani developed new techniques for statistical analysis of space-time data, including air pollution and ground water contamination data. The budget of this project was the highest amount awarded by the NSF's "U.S. - Industrialized Countries Program for the Exchange of Scientists and Engineers" in 1987.

Title:	Geostatistical Evaluation of Flow Analytes
Sponsor:	U.S. Geological Survey
Duration:	(4/1/90 - 3/31/91)
Subject:	Dr. Rouhani developed techniques for efficient estimation of ground water flow Analytes based on available hydrogeological field data.

Title:	Multivariate Geostatistical Trend Detection and Network Design for Acid Deposition Data
Sponsor:	U.S. Environmental Protection Agency
Duration:	(3/1/1991 -9/30/1991)
Subject:	Dr. Rouhani developed a multivariate geostatistical technique for trend detection in acid deposition data and spatial evaluation of current national network, known as NAPD/NTN.

Title:	Multilayer Geostatistical Ground Water Flow and Transport Modeling
Sponsor:	HazLab, Inc.
Duration:	(6/20/92 -12/30/92)
Subject:	Dr. Rouhani developed a combined deterministic/geostatistical groundwater flow/transport model.

Title:	Velocity/Lithology Model Database, Statistical Models of Soil Columns Velocity, and Maps of Model Layers
Sponsor:	Westinghouse Savannah River Company / U.S. DOE
Duration:	(1/1/1993-6/30/1993)
Subject:	Dr. Rouhani developed a relational database and conducted extensive geostatistical analyses of seismic data.

Title:	Application of Geostatistical Methods to SRS Groundwater Monitoring and Environmental Risk
Sponsor:	Westinghouse Savannah River Company / U.S. DOE
Duration:	(7/1/1993-10/15/1993)
Subject:	Dr. Rouhani developed procedures for evaluation of the adequacy of groundwater quality data at a waste site.

Title:	H-Area/ITP Geostatistical Assessment of In-situ and Engineering Properties
Sponsor:	Westinghouse Savannah River Company / U.S. DOE
Duration:	(1/1/1994-6/30/1995)
Subject:	Dr. Rouhani will develop geostatistical estimation/simulation procedure in support of seismic modeling of the site.

PUBLICATIONS

Published Books and Parts of Books

1. Rouhani, S., and T.J. Hall, "Geostatistical Schemes for Groundwater Quality Management in Southwest Georgia," in Pollution, Risk Assessment, and Remediation in Groundwater Systems, pp. 197-223, R.M. Khanbilvardi and J. Fillos, Eds., Scientific Publications Co., Washington, DC, 1987.
2. Rouhani, S., and R. Kangari, "Landfill Site Selection," in Expert Systems: Applications to Urban Planning, Ch. 10, T.J. Kim et al., Eds., Springer-Verlag, 1989.
3. Lennon, G.P., and S. Rouhani, Eds., Ground Water, Proceedings of the ASCE International Symposium on Ground Water, ASCE, 1991.
4. Rouhani, S., R. Srivastava, A. Debarats, M. Cromer, and I. Johnson, Eds., “Geostatistics for Environmental and Geotechnical Applications,” STP 12 83, ASTM, 1996.
5. Wellington, B., and Rouhani S., “Environmental Statistics,” in Sustainable Land Development and Restoration: Decision Consequence Analysis, pp. 311-323, K. Brown et al., Eds., Butterworth-Heinemann, New York, NY, 2010.

6. Uhler, A.D., Stout, S.A., Emsbo-Mattingly, S.D., and Rouhani S., "Chemical Fingerprinting: Streamlining Site Assessment during the Sustainable Redevelopment Process," in Sustainable Land Development and Restoration: Decision Consequence Analysis, pp. 311-323, K. Brown et al., Eds., Butterworth-Heinemann, New York, NY, 2010.

Standards and Guidance Documents (Main Author/Contributing Author)

1. American Society of Testing and Materials (ASTM), Standard Guide for Reporting Geostatistical Site Investigations, D5549-94, 1994.
2. American Society of Testing and Materials (ASTM), Standard Guide for Analysis of Spatial Variation in Geostatistical Site Investigations, D5922-96, 1996.
3. American Society of Testing and Materials (ASTM), Standard Guide for Selection of Kriging Methods in Geostatistical Site Investigations, D5923-96, 1996.
4. American Society of Testing and Materials (ASTM), Standard Guide for Selection of Simulation Approaches in Geostatistical Site Investigations, D5924-96, 1994.
5. Department of Navy (DON), Guidance for Environmental Background Analysis, Volume I: Soil, NFESC User's Guide, UG-2049-ENV, April 2002.
6. Department of Navy (DON), Guidance for Environmental Background Analysis, Volume II: Sediment, NFESC User's Guide, UG-2054-ENV, April, 2003.
7. Department of Navy (DON), Guidance for Environmental Background Analysis, Volume III: Groundwater, NFESC User's Guide, UG-2059-ENV, April, 2004.
8. Department of Navy (DON), Guidance for Environmental Background Analysis, Volume IV: Vapor Intrusion Pathway, User's Guide, UG-2091-ENV, Interim Final, April 2011.
9. United States Environmental Protection Agency (US EPA), *Guidance for Soil Cleanup Strategies*, Draft, 2003.

Published Journal Papers (refereed)

1. Rouhani, S., "Variance Reduction Analysis", *Water Resources Research*, Vol. 21, No. 6, pp. 837-846, June, 1985.
2. Rouhani, S., "Comparative Study of Ground Water Mapping Techniques", *Journal of Ground Water*, Vol. 24, No. 2, pp. 207-216, March-April 1986.
3. Rouhani, S., and Fiering, M.B., "Resilience of a Statistical Sampling Scheme," *Journal of Hydrology*, Vol. 89, No. 1, pp. 1-11, December, 1986.
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PROFESSIONAL ACTIVITIES

1. American Geophysical Union:
   - Member, 1981-Present.
   - Associate Editor, *Water Resources Research*, 1989-1994.
2. American Society of Civil Engineering:
   - Associate Member, 1983-1987.
   - Member, 1987.
   - Chairman, National Ground Water Hydrology Committee (Standing Committee), Hydraulics Division, Oct. 1991-1992.
   - Chairman, ASCE Task Committee on Geostatistical Techniques in Geohydrology, Ground Water Hydrology Technical Committee, American Society of Civil Engineers, Hydraulics Division, Oct. 1987-Sept. 1989.
   - Contact Member, ASCE Task Committee on Groundwater Monitoring Network Design, Probabilistic Approaches to Hydraulics and Hydrology Committee, Hydraulic Division, Oct. 1988- Sept. 1990.

Secretary, ASCE Water Resources Committee, American Society of Civil Engineers, Georgia Section, 1988.

Special Session Organizer, Special Session on "Development and Applications of Geostatistics in Geohydrology," 1989 ASCE National Conference on Hydraulic Engineering, New Orleans, August 14-18, 1989.

Special Session Organizer and Chairman, Special Session on Geostatistics in Geohydrology, 1990 ASCE Water Resources Conference, Fort Worth, April, 1990.

Symposium Organizer, International Symposium on Ground Water, 1991 ASCE National Conference on Hydraulic Engineering, Nashville, July, 1991.

3. International Water Resources Association: Member, 1985.
4. American Water Resources Association: Member, 1986.
5. North American Council on Geostatistics, 1987.
6. International Geostatistical Association: Member, 1989.
7. Association for Environmental Health and Sciences (AEHS):
   Member, 2003.
   Member of Editorial Board, *Environmental Forensics*, 2003-Present.